Part IV
Protecting Ground Water

Chapter 7: Section C
Designing A Land Application Program

Contents

Designing A Land Application Program

This chapter will help you:

- *Assess the risks associated with waste constituents when considering application directly to the land as a soil amendment, or for treatment, or disposal.*
- *Account for the designated ground-water constituents identified in Chapter 7, Section A—Assessing Risk, as well as other waste parameters such as soil properties and plant and microbial interactions.*
- *Evaluate the capacity of the soil, vegetation, and microbial life to safely assimilate the waste when developing an application rate.*

Land application can be a beneficial and practical method for treating and disposing of some wastes. Because land application does not rely on liners to contain waste, however, there are some associated risks. With proper planning and design, a land application program can meet waste management and land preservation goals, and avoid negative impacts such as noxious odors, long-term damage to soil, and releases of contaminants to ground water, surface water, or the air. This chapter describes and recommends a framework for addressing a variety of waste parameters, in addition to the constituents outlined in Chapter 7, Section A—Assessing Risk,[1] and other factors such as soil properties and plant and microbial nutrient use[2] that can affect the ability of the land to safely assimilate directly applied waste. Successful land application programs address the interactions among all these factors.

Some of the benefits of land application include:

- **Biodegradation of waste.** If a waste stream contains sufficient organic material, plants and microorganisms can significantly biodegrade the waste, assimilating its organic components into the soil. After allowing sufficient time for assimilation of the waste, more waste can be applied to a given site without significantly increasing the total volume of waste at the site. This is in contrast to landfills and waste piles, in which waste accumulates continually and generally does not biodegrade quickly enough to reduce its volume significantly.
- **Inclusion of liquids.** Land application units can accept bulk, non-containerized liquid waste. The water

[1] The constituents incorporated in IWEM, including the heavy metals and synthetic organic chemicals, typically have little or no agricultural value and can threaten human health and the environment even in small quantities. The term "waste parameters" as used in this section refers to some additional constituents such as nitrogen and biodegradable organic matter and other site-specific properties such as pH, that can have considerable agricultural significance and that can significantly impact human health and the environment.

[2] 40 CFR Part 503 specifies requirements for land application of sludge from municipal sewage treatment plants. The Part 503 regulations apply to sewage sludge (now generally referred to as "biosolids") or mixtures of sewage sludge and industrial process wastes, not to industrial wastes alone. Some of the specifications in Part 503, for example those concerning pathogens, might be helpful in evaluating land application of industrial wastes. For mixtures of sewage sludge and industrial waste, the ground-water and air risk assessments and the framework laid out in the Guide can help address constituents that are not covered under the Part 503 regulations.

content of some liquid wastes make them desirable at land application sites in arid climates. When managing liquid waste, land application can reduce the need for expensive dewatering processes.

- **Improvement of soil.** Applying waste directly to land can improve soil quality if the waste contains appropriate levels of biodegradable organic matter and nutrients. Nutrients can improve the chemical composition of the soil to the extent that it can better support vegetation, while biodegradable organic matter can improve its physical properties and increase its water retention capacity. This potential for chemical and physical improvements through land application have led to its use in conditioning soil for agricultural use.

Figure 1 outlines a framework for evaluating land application. This framework incorporates both the ground-water risk assessment methodology recommended in Chapter 7, Section A–Assessing Risk, as well as the other waste parameters and factors important to land application.

I. Identifying Waste Constituents for Land Application

If a waste leachate contains any of the constituents covered in the IWEM ground-water model, you should first check with a federal, state, or other regulatory agency to see if the waste constituents identified in the waste are covered by any permits, MOUs, or other agreements concerning land application. The Guide does not supersede or modify conditions established in regulatory or other binding mechanisms, such as MOUs or agreements.[3]

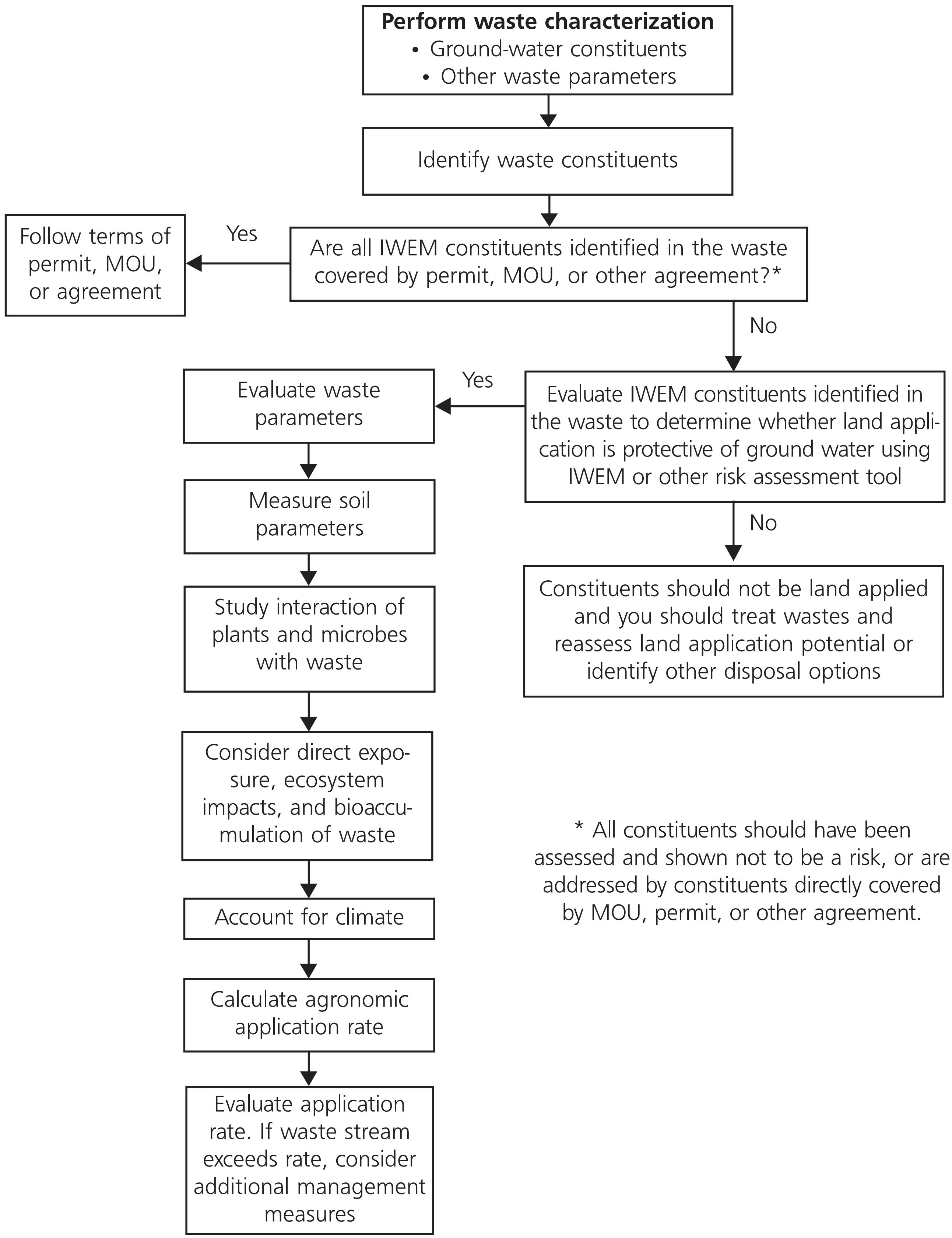
Some wastes might be designated by state or local regulators as essentially equivalent to a manufactured product or raw material. Such designations usually are granted only when use of the designated waste would not present a greater environmental and health risk than would use of the manufactured or raw material it replaces. Equivalence designations are included in the category of "other agreements" above. If there are no designated ground-water constituents other than those on which the designation is based, then the guidelines described in this chapter can help you to determine an appropriate application rate.

If the constituent(s) identified in the waste is not currently covered under an agreement, IWEM or another site-specific model can help you determine whether land application of the constituent(s) will be protective of ground water. In some cases, pollution prevention or treatment can lower constituents levels so that a waste can be land applied. In other cases, land application might not be feasible. In this event, you should pursue other waste management options. If your modeling results indicate that the constituents can be land applied, then the guidelines described in this chapter can once again help you to determine an appropriate application rate.

Your modeling efforts should consider both the direct exposure and ecosystem pathways. These pathways are extremely important in land application since waste is placed on the land and attenuated by the natural environment rather than contained by an engineered structure.

[3] EPA has signed agreements with states, industries, and individual sites concerning land application. One example is EPA's Memorandum of Understanding (MOU) between the American Forest and Paper Association (AFPA) and the U.S. EPA Regarding the Implementation of the Land Application Agreements Among AF&PA Member Pulp and Paper Mills and the U.S. EPA, January 1994. For more information on this MOU contact either AFPA's Director of Industrial Waste Programs at 111 19th Street, N.W., Washington, D.C. 20036 or EPA's Director of the Office of Pollution Prevention and Toxics.

Figure 1. A Recommended Framework for Evaluating Land Application



II. Evaluating Waste Parameters

In addition to the ground-water constituents designated in Chapter 7, Section A–Assessing Risk, you should evaluate the waste's total solids content, pH, biodegradable matter, pathogens, nutrients, metals, carbon to nitrogen ratio, soluble salts, and calcium carbonate equivalent when considering land application. These parameters provide the basis for determining an initial waste application rate and are summarized in Table 1. After the initial evaluation, you should sample and characterize the waste on a regular basis and after process changes that might affect waste characteristics to help determine whether you should change application practices or consider other waste management options.

A. Total Solids Content

Total solids content indicates the ratio of solids to water in a waste. It includes both suspended and dissolved solids, and is usually expressed as a percentage of the waste.

Table 1
Summary of Important Waste Parameters

Waste Parameter	Significance
Total solids content	Indicates ratio of solids to water in waste and influences application method.
pH	Controls metals solubility (and therefore mobility of metals toward ground water) and affects biological processes.
Biodegradable organic matter	Influences soil's water holding capacity, cation exchange, and other physical and chemical properties, including odor.
Nutrients (nitrogen, phosphorus, and potassium)	Affect plant growth; nitrogen is a major determinant of application rate; can contaminate ground water or cause phytotoxicity if applied in excess.
Carbon to nitrogen ratio	Influences availability of nitrogen to plants.
Soluble salts	Can inhibit plant growth, reduce soil permeability, and contaminate ground water.
Calcium carbonate equivalent	Measures a waste's ability to neutralize soil acidity.
Pathogens	Can threaten public health by migrating to ground water or being carried by surface water, wind, or other vectors.
Ground-water constituents designated in Chapter 7, Section A–Risk Assessment including metals and organic chemicals	Can present public health risk through ground-water contamination, direct contact with waste-soil mix, transport by surface water, and accumulation in plants. Metals inhibit plant growth and can be phytotoxic at elevated concentrations. Zinc, copper, and nickel are micronutrients essential to plant growth, but can inhibit growth at high levels.

Total solids content depends on the type of waste, as well as whether the waste has been treated prior to land application. If waste is dried, composted, dewatered, thickened, or conditioned prior to land application, water content is decreased, thereby increasing the total solids content (for some dry, fine, particulate wastes, such as cement kiln dust, conditioning might involve adding water).[4]

Understanding the total solids content will help you develop appropriate storage and handling procedures and establish an application rate. Total solids content also can affect your choice of application method and equipment. Some methods, such as spray irrigation, might not work effectively if the solids content is too high. If it is low, meaning liquid content is correspondingly high, waste transportation costs could increase. If the total solids content of the waste is expected to vary, you can select equipment to accommodate materials with a range of solids content. For example, selecting spreaders that will not clog if the waste is slightly drier than usual will help operations run more efficiently and reduce equipment problems.

Source: Ag-Chem Equipment Co., Inc.
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B. pH

A waste's pH is a measure of its acidic or alkaline quality. Most grasses and legumes, as well as many shrubs and deciduous trees, grow best in soils with a pH range from 5.5 to 7.5. If a waste is sufficiently acidic or alkaline[5] to move soil pH out of that range, it can hamper plant growth. Acidic waste promotes leaching of metals, because most metals are more soluble under acidic conditions than neutral or alkaline conditions. Once in solution, the metals would be available for plant uptake or could migrate to ground water. Alkaline conditions inhibit movement of most metals. Extreme alkalinity, where pH is greater than 11, impairs growth of most soil microorganisms and can increase the mobility of zinc, cadmium, and lead.

Aqueous waste with a pH of 2 or less or a pH of 12.5 or more meets the definition of hazardous waste under federal regulations (40 CFR 261.22(a)). If the pH of a waste makes it too acidic for land application, you can consider adjusting waste pH before application. Lime is often used to raise pH, but other materials are also available. The pH is also important to consider when developing waste handling and storage procedures.

[4] Some states consider composted materials to no longer be wastes. Consult with the regulatory agency for applicable definitions.

[5] A pH of 7 is neutral. Materials with pH less than 7 are acidic, while those with pH greater than 7 are alkaline.

C. Biodegradable Organic Matter

Wastes containing a relatively high percentage of biodegradable organic matter have greater potential as conditioners to improve the physical properties of soil. The percentage of biodegradable organic matter in soil is important to soil fertility, as organic matter can add nutrients; serve as an absorption and retention site for nutrients; and provide chemical compounds, such as chelating agents, that help change nutrients into more plant-available forms. The content of biodegradable organic matter is typically expressed as a percentage of sample dry weight.

Biodegradable organic matter also influences soil characteristics. Soils with high organic matter content often have a darker color (ranging from brown to black), increased cation exchange capacity—capacity to take up and give off positively charged ions—and greater water holding capacity. Biodegradable organic matter also can help stabilize and improve the soil structure, decrease the density of the material, and improve aeration in the soil. In addition, organic nutrients are less likely than inorganic nutrients to leach.

How can biodegradable organic matter affect the waste application rate?

While organic materials provide a significant source of nutrients for plant growth, decomposition rates can vary significantly among materials. Food processing residues, for example, generally decompose faster than denser organic materials, such as wood chips. It is important to account for the decomposition rate when determining the volume, rate and frequency of waste application. Loading the soil with too much decomposing organic matter (such as by applying new waste before a previous application of slowly decomposing waste has broken down) can induce nitrogen deficiency (see section D. below) or lead to anaerobic conditions.

D. Nutrients

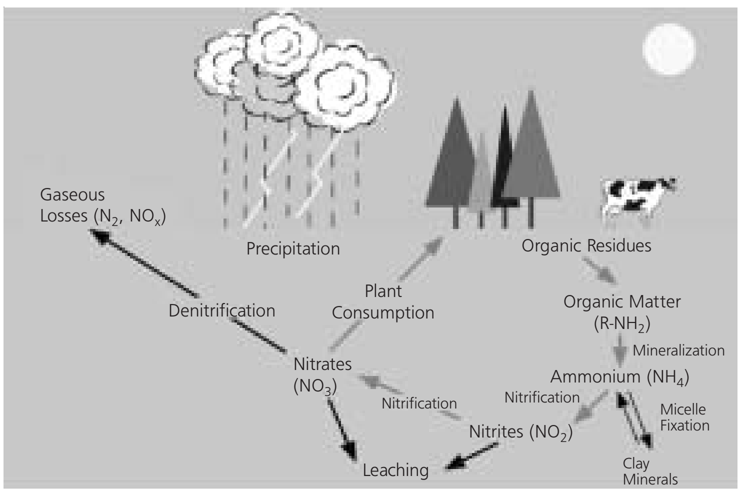
Nitrogen, phosphorus, and potassium are often referred to as primary or macro-nutrients and plants use them in large amounts. Plants use secondary nutrients, including sulfur, magnesium, and calcium, in intermediate quantities. They use micronutrients, including iron, manganese, boron, chlorine, zinc, copper, and molybdenum, in very small quantities. Land application is often used to increase the supply of these nutrients, especially the primary nutrients, in an effort to improve plant growth.

Nutrient levels are key determinants of application rates. Excessive soil nutrient levels, caused by high waste application rates, can be phytotoxic or result in contamination of ground water, soil, and surface water. Nutrient loading is dependent on nutrient levels in both the waste and the soil, making characterization of the soil, as well as of the waste, important.

Nitrogen. Nitrogen content is often the primary factor determining whether a waste is agriculturally suitable for land application, and, if so, at what rate to apply it. Nitrogen deficiency is detrimental to the most basic plant processes, as nitrogen is an essential element for photosynthesis. Sufficient nitrogen promotes healthy growth and imparts a dark green color in vegetation. Lack of nitrogen can be identified by stunted plant growth and pale green or yellowish colored vegetation. Extreme nitrogen deficiency can cause plants to turn brown and die. On the other extreme, excessive nitrogen levels can result in nitrate leaching, which can contaminate ground-water supplies.

Although nitrate poses the greatest threat to ground water, nitrogen occurs in a variety of forms including ammonium, nitrate, nitrite, and organic nitrogen. These forms taken together are measured as total nitrogen. You should account for the ever-occurring nitrogen transformations that take place in the soil before and after waste is applied. These transformations are commonly described as the nitrogen cycle and are illustrated below in Figure 2.

Figure 2. The Nitrogen Cycle



Phosphorus. Phosphorus plays a role in the metabolic processes and reproduction of plants. When soil contains sufficient quantities of phosphorus, root growth and plant maturation improve. Conversely, phosphorus-deficient soils can cause stunted plant growth. Excessive phosphorus can lead to inefficient use of other nutrients and, at extreme levels, zinc deficiency. High phosphorus usage on crops and its associated runoff into surface water bodies has increased the biological productivity of surface waters by accelerating eutrophication, which is the natural aging of lakes or streams brought on by nutrient enrichment.[6] Eutrophication has been identified as the main cause of impaired surface water quality in the United States.

Potassium. Potassium is an essential nutrient for protein synthesis and plays an important role in plant hardiness and disease tolerance. In its ionic form (K^+), potassium helps to regulate the hydration of plants. It also works in the ion transport system across cell membranes and activates many plant enzymes. Like other nutrients, symptoms of deficiencies include yellowing, burnt or dying leaves, as well as stunted plant growth. Symptoms of potassium deficiency also, in certain plants, can include reduced disease resistance and winter hardiness.

How can I take nutrient levels into account?

You should develop a nutrient management plan that accounts for the amount of nitrogen, phosphorus, and potassium being supplied by all sources at a site. The U.S. Department of Agriculture, Natural Resources Conservation Service has developed a conservation practice standard “Nutrient Management” Code 590 that can be used as the basis for your nutrient management plan. The purpose of this standard is to budget and supply nutrients for plant production, to properly utilize manure or organic by-products as a plant nutrient source, to minimize agricultural nonpoint source pollution of surface and ground-water resources, and to maintain or improve the physical, chemical, and biological condition of the soil. Updated versions of this standard can be obtained from the Internet at **<www.nrcs.usda.gov/technical/ECS/nutrient/documents.html>**.

Nitrogen is generally the most limiting nutrient in crop production systems and is added to the soil environment in the greatest

[6] U.S. Department of Agriculture, Agricultural Research Service. *Agricultural Phosphorus and Eutrophication*, 1999. Washington, DC.

amount of any of the plant nutrients. If, however, waste application rates are based solely on nitrogen levels, resulting levels of other nutrients such as phosphorus and potassium can exceed crop needs or threaten ground water or surface water bodies. You should avoid excessive nutrient levels by monitoring waste concentrations and soil buildup of nutrients and reducing the application rate as necessary, or by spacing applications to allow plant uptake between applications. Your local, state, or regional agricultural extension service might have already developed materials on or identified software for nutrient management planning. Consult with them about the availability of such information. Northeast Regional Agricultural Engineering Services (NRAES) Cooperative Extension, for example, has compiled information on nutrient management software programs.[7]

E. Metals

A number of metals are included in IWEM for evaluating ground-water risk. Some metals, such as zinc, copper, and manganese, are essential soil micronutrients for plant growth. These are often added to inorganic commercial fertilizers. At excessive concentrations, however, some of these metals can be toxic to humans, animals, and plants. High concentrations of copper, nickel, and zinc, for example, can cause phytotoxicity or inhibit plant growth. Also, the uptake and accumulation of metals in plants depends on a variety of plant and soil factors, including pH, biodegradable organic matter content, and cation exchange capacity. Therefore, it is important to evaluate levels of these metals in waste, soil, and plants from the standpoint of agricultural significance as well as health and environmental risk.

How can I determine acceptable metal concentrations?

The Tier I and II ground-water models can help you identify acceptable metals concentrations for land application. Also it is important to consult with your local, state, or regional agriculture extension center on appropriate nutrient concentrations for plant growth. If the risk evaluation indicates that a waste is appropriate for land application, but subsequent soil or plant tissue testing finds excessive levels of metals, you can consider pretreating the waste with a physical or chemical process, such as chemical precipitation to remove some metals before application.

F. Carbon-to-Nitrogen Ratio

The carbon-to-nitrogen ratio refers to the relative quantities of these two elements in a waste or soil. Carbon is associated with organic matter, and the carbon-to-nitrogen ratio reflects the level of inorganic nitrogen available. Plants cannot use organic nitrogen, but they can absorb inorganic nitrogen such as ammonium. For many wastes, the carbon-to-nitrogen ratio is computed as the dry weight content of organic carbon divided by the total nitrogen content of waste.

Some wastes rich in organic materials (carbon) can actually induce nitrogen deficiencies. This occurs when wastes provide carbon in quantities that microbes cannot process without depleting available nitrogen. Soil microbes use carbon to build cells and nitrogen to synthesize proteins. Any excess organic nitrogen is then converted to inorganic nitrogen, which plants can use. The carbon-to-nitrogen ratio tells whether excess organic nitrogen will be available for this conversion.

When the carbon-to-nitrogen ratio is less than 20 to 1—indicating a high nitrogen content—organic nitrogen is mineralized, or con-

[7] Nutrient Management Software: Proceedings from the Nutrient Management Software Workshop. To order, call NRAES at 607 255-7654 and request publication number NRAES-100.

verted from organic nitrogen to inorganic ammonium, and becomes available for plant growth. For maximal plant growth, the literature recommends maintaining a ratio below 20 to 1. When the carbon-to-nitrogen ratio is in the range of 20 to 1 to 30 to 1—a low nitrogen content—soil micro-organisms use much of the organic nitrogen to synthesize proteins, leaving only small excess amounts to be mineralized. This phenomenon, known as immobilization, leaves little inorganic nitrogen available for plant uptake. When the carbon-to-nitrogen ratio is greater than 30 to 1, immobilization is the dominant process, causing stunted plant growth. The period of immobilization, also known as nitrogen or nitrate depression, will vary in length depending on the decay rate of the organic matter in the waste. As a result, plant growth within that range might not be stunted, but is not likely to be maximized.

How can I manage changing carbon-to-nitrogen ratios?

The cycle of nitrogen conversions within the soil is a complex, continually changing process (see Figure 2). As a result, if applying waste based only on assumed nitrogen mineralization rates, it is often difficult to ensure that the soil contains sufficient inorganic nitrogen for plants at appropriate times. If you are concerned about reductions in crop yield, you should monitor the soil's carbon-to-nitrogen ratio and, when it exceeds 20 to 1, reduce organic waste application and/or supplement the naturally mineralized nitrogen with an inorganic nitrogen fertilizer, such as ammonium nitrate. Methods to measure soil carbon include EPA Method 9060 in *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods—SW-846*. Nitrogen content can be measured with simple laboratory titrations.

G. Soluble Salts

The term soluble salts refers to the inorganic soil constituents (ions) that are dissolved in the soil water. Major soluble salt ions include calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), chloride (Cl^{-}), sulfate (SO_4^{2-}), bicarbonate (HCO_3^{-}), and nitrate (NO_3^{-}). Total dissolved solids (TDS) refers to the total amount of all minerals, organic matter, and nutrients that are dissolved in water. The soluble salt content of a material can be determined by analyzing the concentration of the individual constituent ions and summing them, but this is a lengthy procedure. TDS of soil or waste can reasonably be estimated by measuring the electrical conductivity (EC) of a mixture of the material and water. EC can be measured directly on liquid samples. TDS is found by multiplying the electrical conductivity reading in millimhos/cm (mmhos/cm) by 700 to give TDS in parts per million (ppm) or mg/l.

Soluble salts are important for several reasons. First, saline soil, or soil with excessive salt concentrations, can reduce plant growth and seed germination. As salt concentration in soil increases, osmotic pressure effects make it increasingly difficult for plant roots to extract water from the soil. Through a certain range, this will result in reduced crop yield, up to a maximum beyond which crops will be unable to grow. The range and maximum for a few representative crops are shown in Table 2. For this reason, the salt content of the waste, rather than its nitrogen content, can be the primary determinant of its agricultural suitability for land application, especially on irrigated soils in arid regions.

The second reason soluble salts are important is that sodic soil, or soil with excessive levels of sodium ions (Na^{+}) relative to divalent ions (Ca^{2+}, Mg^{2+}), can alter soil structure and reduce soil permeability. The sodium absorption rate (SAR) of a waste is an indicator of its sodicity. To calculate the SAR of a

Table 2:
Salinity Tolerance of Selected Crops

Crop	Soil Salinity (mmhos/cm)[a] that will result in:		
	0% yield reduction[b]	50% yield reduction[b]	100% yield reduction[b]
Alfalfa	2.0	8.8	16
Bermuda grass	6.9	14.7	23
Clover	1.5	10.3	19
Perennial rye	5.6	12.1	19
Tall fescue	3.9	13.3	32

Source: Borrelli, J. and D. Brosz. 1986. Effects of Soil Salinity on Crop Yields.

[a] A rule of thumb from the irrigation industry holds that soil salinity will be 1½ times the salinity of applied irrigation water. The effect that waste salinity will have on soil salinity, however, is not as easily predicted and depends on the waste's water content and other properties and on the application rate.

[b] Reductions are stated as a percentage of maximum expected yield.

waste or soil, determine the Na^+, Ca^{2+}, and Mg^{2+} concentrations in milliequivalents per liter[8] for use in the following equation:[9]

$$SAR = \frac{Na^+}{\sqrt{\frac{1}{2}(Ca^{2+} + Mg^{2+})}}$$

Soils characterized by both high salts (excessive TDS as indicated by EC) and excessive sodium ions (excessive Na^+ as indicated by SAR) are called saline-sodic soils, and can be expected to have the negative characteristics of both saline soils and sodic soils described above. Table 3 displays EC and SAR levels indicative of saline, sodic, and saline-sodic soils.

The third reason soluble salts are important is that specific ions can induce plant toxicities or contaminate ground water. Sodium and chloride ions, for example, can become phytotoxic at high concentrations. To assess sodic- or toxic-inducing characteristics, you should conduct an analysis of specific ions in addition to measuring EC.

What can I do if a waste is either saline or sodic?

Saline waste. If a waste is saline, careful attention to soil texture, plant selection, and application rate and timing can help. Coarse soils often have a lower clay content and are less subject to sodium-induced soil structure

[8] The term milliequivalents per liter (meq/l) expresses the concentration of a dissolved substance in terms of its combining weight. Milliequivalents are calculated for elemental ions such as Na^+, Ca^{2+}, and Mg^{2+} by multiplying the concentration in mg/l by the valence number (1 for Na^+, 2 for Ca^2+ or Mg^{2+}) and dividing by the atomic weight (22.99 for Na^+, 40.08 for Ca^{2+}, or 24.31 for Mg^{2+}).

[9] If the proper equipment to measure these concentrations is not available, consider sending soil and waste samples to a soil testing laboratory, such as that of the local extension service (visit **<www.reeusda.gov/statepartners/usa.htm>** for contact information) or nearby university. Such a laboratory will be able to perform the necessary tests and calculate the SAR.

Table 3
EC and SAR Levels Indicative of Saline, Sodic, and Saline-Sodic Soils

Soil Characterization			
Normal	**Saline**	**Sodic**	**Saline-Sodic**
EC[a] < 4 and SAR[b] < 13	EC > 4	SAR> 13	EC > 4 and SAR > 13

Source: Fipps, G. Managing Irrigation Water Salinity In the Lower Rio Grande Valley.
[a]In units of mmhos/cm [b]dimensionless

problems. While coarse soils help minimize soil structural problems associated with salinity, they also have higher infiltration and permeability rates, which allow for more rapid percolation or flushing of the root zone. This can increase the risk of waste constituents being transported to ground water.

Since plants vary in their tolerance to saline environments, plant selection also is important. Some plant species, such as rye grass, canary grass, and bromegrass, are only moderately tolerant and exhibit decreased growth and yields as salinity increases. Other plants, such as barley and bermuda grass, are more saline-tolerant species.

You should avoid applying high salt content waste as much as possible. For saline wastes, a lower application rate, and thorough tilling or plowing can help dilute the overall salt content of the waste by mixing it with a greater soil volume. To avoid the inhibited germination associated with saline soils, it also can help to time applications of high-salt wastes well in advance of seedings.

Sodic waste. SAR alone will not tell how sodium in a waste will affect soil permeability; it is important to investigate the EC of a waste as well. Even if a waste has a high SAR, plants might be able to tolerate this level if the waste also has an elevated EC. As with saline waste, for sodic waste select a coarser-textured soil to help address sodium concerns. Adding gypsum ($CaSO_4$) to irrigation water can also help to reduce the SAR, by increasing soil calcium levels. Although this might help address sodium-induced soil structure problems, if choosing to add constituents to alter the SAR, the EC should also be monitored to ensure salinity levels are not increased too much.

H. Calcium Carbonate Equivalent

Calcium carbonate equivalent (CCE) is used to measure a waste's ability to neutralize soil acidity—its buffering capacity—as compared with pure calcium carbonate. Buffering capacity refers to how much the pH changes when a strong acid or base is added to a solution. A highly buffered solution will show only a slight change in pH when strong acids or bases are added. Conversely, if a solution has a low buffering capacity, its pH will change rapidly when a base or acid is added to it. If a waste has a 50 percent CCE, it would need to be applied at twice the rate of pure calcium carbonate to achieve the same buffering effect.

I. Pathogens

Potential disease-causing microorganisms or pathogens, such as bacteria, viruses, protozoa, and the eggs of parasitic worms, might be present in certain wastes. Standardized testing procedures are available to help determine whether a waste contains pathogens. You should consider using such tests especially if your process knowledge indicates that a waste might contain pathogens. Fecal coliform bacteria can be quantified, for example, by using a membrane filtering technique, which involves passing liquid waste through a filter, incubating the filtrate (which contains the bacteria) on a culture medium for 24 hours, and then counting the number of bacterial colonies formed.

How can I reduce pathogenic risks?

Methods to reduce pathogenic risk include disinfecting or stabilizing a waste prior to land application. Examples of treatment methods recognized for sewage sludge stabilization are included in the sidebar. Pathogens present a public health hazard if they are transferred to food or feed crops, contained in runoff to surface waters, or transported away from a land application site by vectors. If pathogen-carrying vectors are a concern at a site, it is important to establish measures to control them. For examples of methods to control vectors, refer to Chapter 8–Operating the Waste Management System. Additional information on pathogen reduction and methods to control vectors can be obtained from 40 CFR 503.15 and 40 CFR 503.32 (EPA's Sewage Sludge Rule.) A discussion of these alternatives is available in EPA's guidance document *Land Application of Sewage Sludge: A Guide for Land Appliers on the Requirements of the Federal Standards for the Use or Disposal of Sewage Sludge, 40 CFR Part 503* (U.S. EPA, 1994a).

The services of a qualified engineer might be necessary to design an appropriate process for reducing pathogens in a waste. You should consult with the state to determine whether there are any state-specific requirements for pathogen reductions for specific waste types.

What are methods for stabilizing waste prior to land application?

The following methods, recommended for stabilizing sewage sludge, can also be useful for reducing pathogens in waste:

- Aerobic digestion
- Air drying
- Anaerobic digestion
- Composting
- Lime stabilization

More detailed information on each of these and other methods can be found in EPA's *Control of Pathogens and Vector Attraction in Sewage Sludge* (U.S. EPA, 1992).

III. Measuring Soil Properties

Physical, biological, and chemical characteristics of the soil are key factors in determining its capacity for waste attenuation. If the soil is overloaded, rapid oxygen depletion, extended anaerobic conditions, and the accumulation of odorous and phytotoxic end-products can impair soil productivity and negatively impact adjacent properties. With proper design and operation, waste can be successfully applied to almost any soil; however, sites with highly permeable soil (e.g., sand), highly impermeable soil (e.g., clay), poorly drained soils, or steep slopes can present special design issues. Therefore, it is advisable to give such sites lower priority during the site selection process.

How can I evaluate the soil at a site?

To help evaluate the soil properties of a site, you should consult the U.S. Department of Agriculture (USDA) soil survey for the prospective area. These surveys provide information on properties such as soil type and permeability. USDA has prepared soil surveys for most counties in each state. To obtain a copy of the survey for an area, contact the Natural Resource Conservation Service offices, the county conservation district, the state agricultural cooperative extension service, or local health authorities/planning agency. These soils surveys will help during site selection; however, conditions they describe can differ from the actual soil conditions.

Several guidance documents on soil surveys are also available from USDA. These documents include the *National Soil Survey Handbook* and the guide *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys*. The *National Soil Survey Handbook* provides an abundance of information including help on interpreting soil surveys, a primer on soil properties and soil quality, and guides for predicting the permeability of your soil. Both of these documents are available over the Internet and can be obtained from **<www.ftw.nrcs.usda.gov/tech_ref.html>**.

For more site-specific data on actual soil conditions, you can sample and characterize the soil. It might be desirable to have a qualified soil scientist perform this characterization, which often includes soil texture, percentage of organic matter, depth to water table, soil pH, and cation exchange capacity. At a minimum, you should characterize samples from an upper soil layer, 0 to 6 inches, and a deeper soil layer, 18 to 30 inches, and follow established soil sampling procedures to obtain meaningful results. If a detailed characterization is desired, or if it is suspected soil types vary considerably, further subdivision of soil horizons or collection of samples over a greater variety of depths might be appropriate. For more information about how to obtain representative soil samples and to submit them for analysis, you can consult EPA's *Laboratory Methods for Soil and Foliar Analysis in Long-Term Environmental Monitoring Programs* (U.S. EPA, 1995d), or state guides, such as Nebraska's *Guidelines for Soil Sampling*, G91-1000.

Why are chemical and biological properties of soil important?

Chemical and biological properties of the soil, like those of the waste, influence the attenuation of waste constituents. These properties include pH, percentage of organic matter, and cation exchange capacity. Affected attenuation processes in the soil include absorption, adsorption, microbial degradation, biological uptake, and chemical precipitation. For example, adsorption—the process by which molecules adhere to the surface of other particles, such as clay—increases as the cation exchange capacity and pH of the soil increase. Cation exchange capacity, in turn, is dependent on soil composition, increasing as the clay content of the soil increases. Adsorption through cation exchange is an important means of immobilizing metals in the soil. Organic chemicals, on the other hand, are negatively charged and can be adsorbed through anion exchange, or the exchange of negative ions. A soil's capacity for anion exchange increases as its pH decreases.

Why are physical properties of soil important?

Physical properties of the soil such as texture, structure, and pore-size distribution affect infiltration rates and the ability of soil to filter or entrap waste constituents. Infiltration and permeability rates decrease as clay content increases. Sites with soils with permeabilities that are too high or too low have lower land application potential. Soils with high permeability can allow wastes to move through without adequate attenuation. Soils with low permeability can cause pooling or excessive surface runoff during intense rainstorms. Excessive runoff conditions can be compensated for somewhat by minimizing surface slope during site selection. Soils with low permeability are also prone to hydraulic overloading.

The amount of liquid that can be assimilated by a soil system is referred to as its hydraulic loading capacity. In addition to a soil's permeability, hydraulic loading capacity is dependent on other factors such as climate, vegetation, site characteristics, and other site-specific soil properties such as soil type, depth to seasonally high water table, slope and erodibility, water intake rate, and underlying geology and hydrogeology. Exceeding the hydraulic loading capacity of a site, can lead to rapid leaching of waste constituents into ground water, reduction in biological activity, sustained anaerobic conditions, soil erosion, and possible contamination of surface waters. It can also result in excessive evaporation, which can cause excessive odor and unwanted airborne emissions. In order to avoid hydraulic overloading at a site, application of liquid or semi-liquid waste or wastewater should be managed so uncontrolled runoff or prolonged saturation of the soil does not occur.

An important indicator of soil properties is its topography, which affects the potential for soil erosion and contaminated surface-water runoff. Soils on ridge tops and steep slopes are typically well drained, well aerated, and shallow. Steep slopes, however, increase the likelihood of surface runoff of waste and of soil erosion into surface waters. State guidelines, therefore, often specify the maximum slopes allowable for land application sites for various waste characteristics, application techniques, and application rates. The agencies that regulate land application in a state can provide specific guidance concerning slopes. Soils on concave land and broad flat lands, on the other hand, frequently are poorly drained and can be waterlogged during part of the year. Soils in relatively flat areas can have intermediate properties with respect to drainage and runoff and could be more suitable for land application.

IV. Studying the Interaction of Plants and Microbes with Waste

The next step in the design of a land application unit is to consider the plants and microbes at the site and how they will interact with the waste. This interaction includes the uptake and degradation of waste constituents, the effects of the wastes on plant and microbial growth, and changes that can occur in plants or crops affecting their use as food or feed. The uptake of nutrients by plants and microbes on plant roots or in soil affects the rate of waste assimilation and biodegradation, usually increasing it.

It might be necessary to conduct greenhouse or field studies or other tests of plants, soil, and microbes to understand and quantify these interactions. You should consult with the state agricultural department, the local health department, and other appropriate agencies if considering land application of wastes containing designated ground-water constituents or other properties that are potentially harmful to food or feed crops. Industry groups might also be able to provide information about plants with which they have land application experience.

A. Greenhouse and Field Studies

State agricultural extension services, departments of environmental protection, or public universities might have previous studies about plant uptake of nutrients, especially nitrogen, phosphorus, and potassium, but it is important to recognize that the results of studies conducted under different conditions (such as different waste type, application rate, plant type, or climate) are only partially relevant to a specific situation. Furthermore, most studies to date have focused on relatively few plant species, such as corn, and only a handful of constituents, typically metals. Greenhouse studies or pilot-scale field studies attempt to model site-specific conditions by growing the intended crops in soil from the prospective application site. These studies are useful because individual parameters can be varied, such as plant type and waste application rate, to determine the effects of each factor. Additionally, greenhouse or field studies might be required by some states to certify that a waste has agricultural benefits. Generally, the first point of contact for assistance with studies is the state agricultural extension service. Many state extensions can conduct these studies; others might be able to provide guidance or expertise but will recommend engaging a private consultant to conduct the studies.

How do I conduct greenhouse or field studies?

Currently, no national guidelines exist for conducting greenhouse or field studies,[10] but check to see if the state has guidance on accepted practices. Working with a state agricultural extension service or a local university will provide the benefit of their expertise and experience with local conditions, such as which plants are suitable for local soils and climate. If a particular industry sector has a large presence in a state, the state agricultural extension service might have previous experience with that specific type of waste.

Greenhouse studies. Aside from their smaller scale, greenhouse studies differ from field studies primarily in that they are conducted indoors under controlled conditions, while field studies are conducted under natural environmental conditions. A greenhouse study typically involves distributing representative soil samples from the site into several pots to test different application rates, application methods, and crops. Using several duplicate pots for each rate, method, or crop allows averaging and statistical aggregating of results. It is also important to establish control pots, some with no waste and no plants, others with waste but no plants (to observe the extent to which waste assimilation effects are due to soil and pre-existing microbes) and still others with plants but without waste (as a baseline for comparison with waste-amended plant growth).

To the extent feasible, temperature, moisture, and other parameters should simulate actual site conditions. There should be a series of several duplicate pots grown with each combination of plant type, application rate, and other parameters. Pots should be arranged to avoid environmental conditions disproportionately affecting one series of pots. For example, you should avoid placing a whole series of pots in a row closest to a light source; instead, it is better to place one pot from each of several series in that row or randomize placement of pots.

The controlled greenhouse environment allows the study of a wide range of waste-soil

[10] Based on conversations with Dr. Rufus L. Chaney and Patricia Milner, U.S. Department of Agriculture.

interactions without risking the loss of plants due to weather, animal hazards, and other environmental influences. At the same time, this can introduce differences from actual conditions. Root confinement, elevated soil temperature, and rapidly changing moisture levels, for example, can increase the uptake of pollutants by potted plants compared to uptake under field conditions.[11]

Field studies. Field studies, on the other hand, can test application rates and crops on plots at the actual proposed site. As with greenhouse studies, duplicate plots are useful for statistical purposes, and controls are needed. Field study data can be more useful because it more closely reflects real-world conditions, but it also can be more difficult to obtain because of uncontrollable circumstances such as flooding or unusual pest damage that can occur at the time of the study. Field studies also can be subject to siting, health and safety, and permitting requirements.

Field studies also help determine the actual land area required for land application and the quality of runoff generated. Soil and ground-water monitoring help to confirm that waste constituents are being taken up by plants and not leaching into the ground water. Results from field studies, however, might not be duplicated on actual working plots after multiple waste applications, due to long-term soil changes. Crop yields also can vary by as much as 15 to 25 percent under field conditions, even with good fertility and management.

Both greenhouse and field studies typically include extensive sampling of waste, soil before application, plants or representative parts of plants, soil after application, growth of plants, and, to the extent feasible, water. You should sample soil at the surface and in lower horizons using core sampling. Some soil tests require mixing samples with water to form a paste or slurry. Plant tissue tests often require dry-weight samples, made by drying cut plants at about 65°C. Water can be collected in lysimeters (buried chambers made from wide perforated pipe) and removed using hand pumps.

The effects of waste on organisms in the soil can also be monitored during greenhouse and field studies. The literature suggests, that the effects of waste on earthworms are a good indicator of effects on soil organisms in general. It might be worthwhile, therefore, to stock greenhouse pots or field study plots with earthworms at the beginning of a study and monitor the waste constituent levels and the effects on the worms during and at the end of the study. Although these brief studies will not effectively model long-term exposure to waste constituents, it is possible to gauge short-term and acute effects.

B. Assessing Plant and Microbial Uptake Rates

Plants. After performing studies, you should measure the amounts of various nutrients, metals, and other constituents in tissue samples from plants grown in the greenhouses or on test plots. This tells approximately how much of these constituents the plants extracted from the soil-waste mix. By measuring plant-extracted quantities under these various conditions, you can determine a relationship between

[11] If a waste contains VOCs, ensure the possibility of VOCs accumulating within the enclosed greenhouse is addressed.

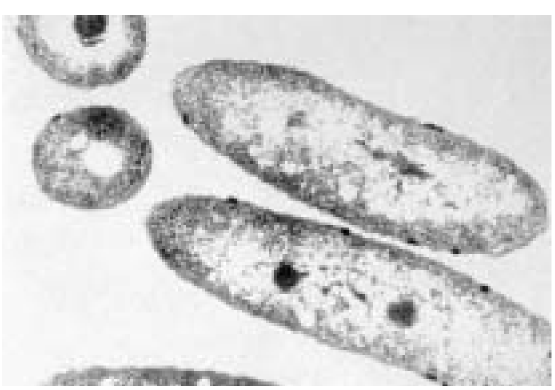
plant type, application rate, and nutrient extraction. From this, you can choose the conditions which result in the desired uptake rate while avoiding uptake of designated ground-water constituents at undesirable concentrations. Plant uptake is often measured as a ratio of the pollutant load found in the plants to the pollutant load applied to the land as illustrated below:

$$\frac{\mu g \text{ pollutant}}{g \text{ dry plant tissue}} \text{ per } \frac{kg \text{ pollutant}}{\text{hectare}}$$

This ratio serves to place pollutant uptake in the context of the original amount of pollutant applied.

In choosing plants for a land application unit, you should also consider growing seasons in relation to periods of waste application rate. Specific waste application rates associated with corresponding uptakes of nutrients by plants, as indicated in greenhouse or field studies, are applicable only during the growing phases covered by the study. At other times, waste application might be infeasible because plants are not present to help assimilate waste, or because plants are too large to permit passage of application equipment without sustaining damage.

Microbes. Certain microbes can biodegrade organic chemicals and other waste constituents. Some accomplish this by directly using the constituents as a source of carbon and energy, while others co-metabolize constituents in the process of using other compounds as an energy source. Aerobic microorganisms require oxygen to metabolize waste and produce carbon dioxide and water as end products. Anaerobic microbes function without oxygen but produce methane and hydrogen sulfide as end products. These gases can present a safety risk as well as environmental threats, and hydrogen sulfide is malodorous. For these reasons, it is recommended that you maintain conditions that favor aerobic microbes.



For many microorganisms, these conditions include a pH of 6 to 8 and temperatures of 10°C to 30°C. In addition, microbes might be unable to transfer oxygen from soil efficiently if the moisture content is near saturation, or they might be unable to obtain sufficient water if the soil is too dry. A water content of 25 to 85 percent of the soil's water holding capacity is recommended in the literature. Oxygen generally is available through diffusion from the atmosphere, but this mechanism might provide insufficient oxygen if there is too little pore space (less than 10 percent of soil volume) or if so much organic matter is applied that oxygen is consumed faster than it is replaced.

C. Effects of Waste on Plant and Microbe Growth

Greenhouse and field studies can tell what effect the waste will have on plant growth patterns. A typical method of quantifying plant growth is to state it in terms of biomass production, which is the dry weight of the cut plants (or representative parts of the plants). If the plants grown with waste applications show greater mass than the control plants,[12] the waste might be providing useful nutrients or otherwise improving the soil. If the plants grown with waste applied at a certain rate

[12] Trends detected in studies assume that results have been subjected to tests of statistical validity before finding a trend significant.

weigh less than the controls, some constituent(s) in the waste might be excessive at the studied application rate. Comparing the results from several different application rates can help find the rate that maximizes growth and avoids detrimental and phytotoxic effects.

Analyzing soil and water after plant growth allows for a comparison between the planted pots or plots against the control to discern the differences due to plant action. If water samples show excessive nutrient (especially nitrogen) levels at a certain application rate, this might indicate that the plants were unable to use all the nutrients in the waste applied at that rate, suggesting that the application was excessive. If soil and water tests show that constituents are consumed, and if other possible causes can be ruled out, microbes might be responsible. Further investigation of microbial action might involve sampling of microbes in soil, counting their population, and direct measurement of waste constituents and degradation byproducts.

D. Grazing and Harvesting Restrictions

If a waste might contain pathogens or designated ground-water constituents, and the established vegetative cover on the land application site is intended for animal consumption, it is important to take precautions to minimize exposure of animals to these contaminants. This is important because animals can transport pathogens and ground-water constituents from one site to another, and can be a point of entry for waste constituents and pathogens into the food chain.

If harvesting crops from a unit for use as animal fodder, you should test plants for the presence of undesirable levels of the designated ground-water constituents before feeding. Grazing animals directly on a unit is discouraged by some states.[13] If considering direct grazing, you should consult with the state to see if there are any restrictions on this practice. Growing crops for human consumption on soil amended with waste calls for even greater caution. In some states, this practice is prohibited or regulated, and in states where it is allowed, finding food processors or distributors willing to purchase such crops can be difficult.

When testing crops before feeding them to animals, local agricultural extension services might be able to help determine what levels are appropriate for animal consumption. If plant tissue samples or findings of a fate and transport model indicate waste constituent levels inappropriate for animal consumption, it is important that you not use harvested plants as fodder or allow grazing on the site. Additionally, plants with high constituent levels will probably be inappropriate for other agricultural use, and thus would likely necessitate disposal of such crops as a waste after harvest.

V. Considering Direct Exposure, Ecosystem Impacts, & Bioaccumulation of Waste

You should evaluate the impacts that your land application unit will have on direct exposure and ecological pathways as well as the potential for bioaccumulation of land-applied waste. During the land application unit's active life, direct human exposure to waste or waste-amended soil is primarily a risk to personnel involved in the operation. You should follow OSHA standards and ensure that personnel are properly trained and use proper protective clothing and equip-

[13] Grazing can also be unwise due to potential effects on soil physical structure. The weight of heavy animals can compact soil, decreasing pore space, which can reduce the soil's waste attenuation capacity.

ment when working onsite. You should limit direct exposure to others through steps such as access control and vehicle washing to prevent tracking waste and waste amended soil off site.

Access control will also limit exposure of some animals. If crops will be used for animal fodder or grazing, you should test harvested fodder for the designated ground-water constituents before use and restrict grazing times. After a site is closed, there might be long-term access risks to future land uses and the general public. To minimize these risks, long-term access controls or deed restrictions might be appropriate. Consult Chapter 11—Performing Closure and Post-Closure Care for further information.

Direct exposure of native animals is often impossible to control and might be an entry point for the ground-water constituents into the food chain. Worms, for example, might be present in the soil and take in these constituents. Birds or other animals could then consume the worms, bioaccumulate, or be transported off site. Furthermore, animals can ingest plants grown on waste-amended soil. Therefore, you should also consider pathways such as these in evaluating your plans for land application.

VI. Accounting for Climate

Local climate considerations should also enter into your land application planning process. For example, wastes that are high in soluble salts are less appropriate and can have deleterious effects in arid climates due to the osmotic pressure from the salts inhibiting root uptake of water. On the other hand, the downward movement of water in the soil is minimal in arid climates, making the migration of waste constituents to ground water less likely.

Climate also determines which plants can grow in a region and the length of the growing season. If the local climate cannot support the plants that might be most helpful in assimilating the particular constituents in a given waste, the use of land application might be limited to other crops at a lower application rate. If the climate dictates that the part of the growing cycle during which land application is appropriate is short, a larger area for land application might be necessary.

There are also operating considerations associated with climate. Since waste should not be applied to frozen or very wet soil, the application times can be limited in cold or rainy climates. In climates where the ground can freeze, winter application poses particular problems even when the ground is not frozen, because if the ground freezes soon after application, the waste that remained near the soil surface can run off into surface waters during subsequent thaw periods. Waste nutrients are also more likely to leach through the soil and into the ground water following spring thaw, prior to crop growth and nutrient uptake. These problems can be partially solved by providing sufficient waste storage capacity for periods of freezing or rainy weather.

VII. Calculating An Agronomic Application Rate

The purpose of a land application unit (i.e., waste disposal versus beneficial use) helps determine the waste application rate best suited for that unit. When agricultural benefits are to be maximized, the application rate is governed by the agronomic rate. The objective for determining an agronomic application rate is to match, as closely as possible, the amount of available nutrients in the waste with the amount required by the crop. One example of an equation for calculating agronomic application rates is:

Agronomic application rate = (Crop nutrient uptake × Crop yield)-Nutrient credits

Where:

Crop nutrient uptake = Amount of nutrients absorbed by a particular crop. These requirements are readily available from your state and local Cooperative Extension Offices

Crop yield = Amount of plant available for harvest. Methods for calculating expected yields include past crop yields for that unit, county yield records, soil productivity tables, or local research.

Nutrient credits = Nitrogen residual from past waste applications, irrigation water nitrate nitrogen, nutrients from commercial fertilizer, and other nitrogen credits from atmospheric deposition from dust and ammonia in rainwater.

In addition, many states and universities have developed their own worksheets or calculations for developing an agronomic application rate. You should check with your state agency to see if you are subject to an existing regulation. In setting a preliminary application rate the crop's nitrogen requirements often serve as a ceiling, but in some cases, phosphorus, potassium, or salt content, rather than nitrogen, will be the limiting factor.

How do I determine the agronomic rate?

Computer models can help determine site-specific agronomic rates. Modeling nitrogen levels in waste and soil-plant systems can help provide information about physical and hydrologic conditions and about climatic influences on nitrogen transformations. Models recommended for use with sewage sludge include Nitrogen Leaching and Economic Analysis Package (NLEAP); DECOMPOSITION; Chemicals, Run-Off, and Erosion from Agricultural Management Systems (CREAMS); and Ground-Water Loading Effects of Agricultural Management Systems (GLEAMS).[14] NLEAP is a moderately complex, field scale model that assesses the potential for nitrate leaching under agricultural fields. NLEAP can be used to compare nitrate leaching potential under different soils and climates, different cropping systems, and different management scenarios. The computer model DECOMPOSITION is specifically designed to help predict sewage sludge nitrogen transformations based on sludge characteristics, as well as climate and soil properties (organic matter content, mean soil temperature, and water potential). Finally, the CREAMS and GLEAMS models, developed by the USDA, are other potentially useful models to assist with site-specific management of land application operations. Additional computer models include Cornell Nutrient Management Planning System (NMPS), Fertrec Plus v 2.1, and Michigan State University Nutrient

[14] All of these models are referenced in EPA's *Process Design Manual: Land Application of Sewage Sludge and Domestic Septage* (U.S. EPA, 1995b). According to that source, the NLEAP software, developed by Shaffer et al., is included in the purchase of *Managing Nitrogen for Groundwater Quality and Farm Profitability* by Follet, et al., which also serves as reference for information on parameters required for nitrogen calculations. Four regional soil and climatic databases (Upper Midwest, Southern, Northeastern, and Western) also are available on disk for use with NLEAP. These materials can be obtained from: Soil Science Society of America Attn: Book Order Department, 677 S. Segoe Road, Madison, WI 53711, 608/273-2021; Book $36.00; Regional Databases $10.00 each. Current updates of the NLEAP program can be obtained by sending original diskettes to: Mary Brodahl, USDA-ARS-GPSR, Box E, Fort Collins, CO 80522. Additional information on the DECOMPOSITION model, developed by Gilmour and Clark, can be obtained from: Mark D. Clark, Predictive Modeling, P.O. Box 610, Fayetteville, AR 72702. The CREAMS and GLEAMS models were developed by USDA.

Management v1.1.[15] If assistance is required in determining an appropriate agronomic rate for a waste, you should contact the regional, state, or county agricultural cooperative extensions, or a similar organization.

VIII. Monitoring

Monitoring ground water can be helpful to verify whether waste constituents have migrated to ground water. Some state, tribal, or other regulatory authorities require ground-water monitoring at certain types of land application units; you should consult with the appropriate regulatory agency to determine whether such a requirement applies to the unit. Even if the unit is not required to monitor ground water, instituting a ground-water monitoring program is recommended for long-term, multiple application units where wastes contain the designated ground-water constituents. Such units are more likely to pose a threat to ground water than are single-application units or units receiving waste without these constituents.

In most cases, lysimeters should be sufficient to monitor ground water. A lysimeter is a contained unit of soil, often a box or cylinder in the ground which is filled with soil, open on the top, and closed at the bottom, so that the water that runs through it can be collected. It is usually more simple and economical to construct and operate than a monitoring well. You can consult with a qualified professional to develop an appropriate ground-water monitoring program for your land application unit.

If ground-water results indicate unacceptable constituent levels, you should suspend land application until the cause is identified. You should then correct the situation that led to the high readings. If a long-term change in the industrial process, rather than a one-time incident, caused the elevated levels, you should reevaluate your use of land application. Adjusting the application rate, adding pretreatment, or switching to another means of waste management might be necessary. After reevaluation, you should examine whether corrective action might be necessary to remediate the contaminated ground water. You should pay particular attention to ensure that applications are not exceeding the soil's assimilative capacity.

You should also consider testing soil samples periodically during the active life of a land application unit. For this testing to be meaningful, it is important that you first determine baseline conditions by sampling the soil before waste application begins. This might already have been done in preparation for greenhouse/field studies or for site characterization. Later, when applying waste to the unit, you should collect and analyze samples at regular intervals (such as annually or after a certain number of applications). Consider analyzing samples for macronutrients, micronutrients, and any of the designated ground-water constituents reasonably expected to be present in the waste. The location and number of sampling points, frequency of sampling, and constituents to be analyzed will depend on site-specific soil, water, plant, and waste characteristics. Local agricultural extension services, which have experience with monitoring, especially when coupled with ground-water monitoring, can detect contamination problems. Early detection allows time to change processes to remedy the problems, and to conduct corrective action if necessary before contamination becomes widespread.

Testing soils after the active life of a unit ends might also be appropriate, especially if the waste is likely to have left residues in the soil. The duration of monitoring after closure, like the location and frequency of monitoring during active life, is site-specific and depends on similar factors. For further information

[15] These models are referenced in the Northeast Regional Agricultural Engineering Cooperative Extension's Nutrient Management Software: Proceedings from the Nutrient Management Software Workshop from December 11, 1996.

about testing soil after the active life of a unit ends, refer to Chapte 11—Performing Closure and Post-Closure Care.

IX. Odor Controls

Odors are sometimes a common problem at land application facilities and an odor management plan can allow facility managers to respond quickly and effectively to deal with odor complaints. A plan should involve working to prevent odors from occurring, working with neighbors to resolve odor complaints, and making changes if odors become an unacceptable condition. The plan should also identify the chemical odor constituents, determine the best method for monitoring odor, and develop acceptable odor thresholds. These odor management plans can be stand-alone plans or part of your company's environmental management system.

To effectively deal with odor complaints, it is important to consider creating an odor detection and response team to identify the source of, and quickly respond to, potential nuisance odor conditions. Document the problem as well as how it was or was not resolved, and notify facility managers as soon as possible. Odor complaints should be documented immediately in terms of the odor's location, characteristics, the time and date, existing meteorological conditions, suspected specific source, information that indicates relative strength compared to other events, and when during the day the odors are noticed.

Measuring odors can be accomplished in two manners: olfactometry and analytical. The olfactometry method uses trained individuals who determine the strength of an odor. Both of these methods have advantages and disadvantages. Some of the advantages of the olfactometry method are that it is accurately correlated with human response, it is fast at providing a general chemical classification, and it is usually cost effective as a field screening method. Disadvantages include the requirement of highly trained individuals, and it does not address the chemistry of the odor problem. Analytical methods use gas chromatographs and mass spectrophotometers to analyze vapor concentrations captured from a sample. Some of the advantages of the analytical method are that it allows detection of odorants at levels near human detection, it is precise and repetitive, and it provides chemical specificity. Disadvantages include a very high capital cost which might not accurately correlate with human responses. You should contact your state for more information on odor management plans and measuring odors.

Designing a Land Application Program Activity List

- ❑ Use the framework to design and evaluate a land application program and to help determine a preliminary waste application rate.
- ❑ Be familiar with waste parameters, such as total solids content, pH, organic matter, nutrients, carbon and nitrogen levels, salts, soil buffering capacity, and pathogens.
- ❑ When examining potential application sites, give special consideration to physical and chemical properties of soil, topography, and any site characteristics that might encourage runoff or odor.
- ❑ Choose crops for the unit considering plant uptake of nutrients and constituents.
- ❑ Account for climate and its effects.
- ❑ Determine an agronomic application rate.
- ❑ Evaluate ground-water and air risks from land application units and consider potential exposure pathways.
- ❑ Consider implementing a ground-water monitoring program and periodic sampling of unit soils.

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